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A STUDY OF THE TECHNICAL FEASIBILITY OF DEVELOPING A STANDARDIZ--ETC(U)
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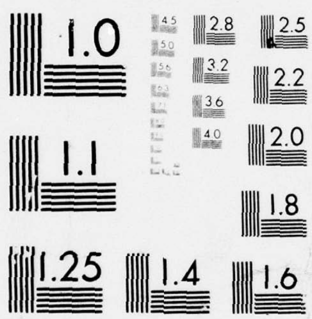
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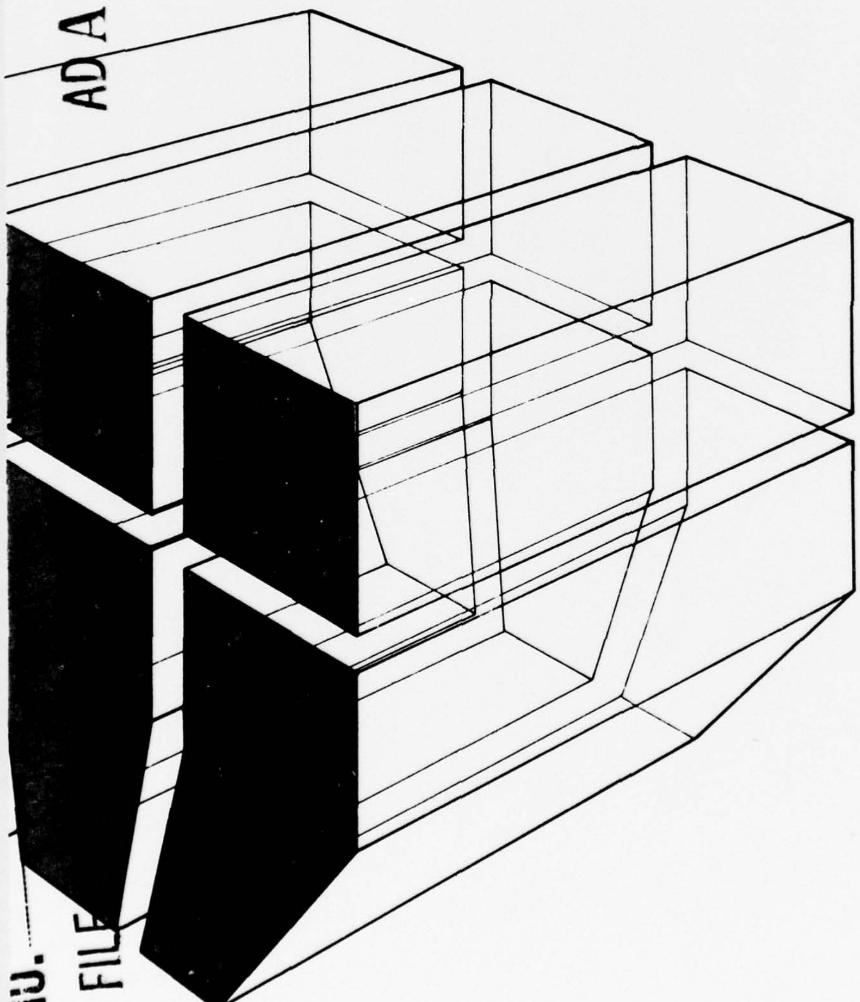
August 1977

A STUDY OF THE TECHNICAL FEASIBILITY OF DEVELOPING A STANDARDIZED ENERGY CONTROL SYSTEM SPECIFICALLY FOR ARMY FACILITIES

by
D. Eng
K. H. Wu



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This report evaluates the feasibility of developing a standardized energy control system (ECS) for monitoring and controlling energy use in Army buildings and facilities. Criteria used in the evaluation were that the system must:

1. Maximize use of off-the-shelf hardware;

2. Use standard software programs and language; → over

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3. Use hardware and software modules which can be easily changed or expanded to insure the user maximum independence of the original equipment manufacturer;

4. Provide reliable real-time facility monitoring and control functions for all types of equipment systems;

5. Minimize number of personnel and skills required for operation;

6. Maintain cost-effectiveness; and

7. Be easy to operate.

Results of the evaluation show that a standardized Army system for energy conservation is feasible and would be cost-effective. Available hardware can be used, but further development is needed to prepare necessary standardized software. The proposed standardized ECS consists of (1) microprocessor-based remote terminals for optimum fail-safe operations, strategically located throughout the installation and capable of monitoring and controlling real-time processes, and (2) a centrally located minicomputer-based console for supervisory energy control activities and data logging. The proposed system would be capable of efficient system modification and expansion and provide good system reliability.

FOREWORD

This study was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), and was funded by Project 4A762719-AT41, "Design Construction and Operations and Maintenance Technology for Military Facilities"; Task T6, "Energy Systems"; and Work Unit 010, "Fixed Facility Energy Control Systems." The study was conducted by the Electrical-Mechanical Branch (EPM), Energy and Power Division (EP), U. S. Army Construction Engineering Research Laboratory (CERL), Champaign, Illinois. The OCE Technical Monitors for this study were Messrs. R. O'Brien and J. Walton, DAEN-FEU/A. The CERL Principal Investigator was Mr. D. Eng.

Appreciation is expressed to Messrs. M. J. Pollock (Chief, EPM), R. G. Donaghy (Chief, EP), James Hall, Gerald Tietz, and Kees Brinkman of CERL for their contributions and guidance.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The need to conserve energy, the increase in energy costs, and the limited funding available for the operation, maintenance, and staffing of Army facilities have necessitated the investigation of energy control systems (ECSs) for use in fixed military facilities.

Continuous energy monitoring with an ECS during a 1-year period can help determine the location and profile of energy consumption and identify areas where additional energy may be conserved. It can also provide the necessary feedback to control and optimize energy consumption in electrical, mechanical, and utility systems in fixed facilities. The capabilities of a computer-based ECS include programmed automated equipment shutoff, outside air shutoff, load shedding, system performance optimization, maintenance scheduling, and other energy management activities.*

Feasibility studies have already shown ECSs to be profitable for many installations,[1-3] and energy savings and the number of installations that can benefit from ECSs will increase with increasing energy costs. A recent article[4] has indicated that a savings of $60,000 for the most recent 30-day energy billing was realized through the use of the newly installed computer-based ECS in the HQ, U.S. Army Missile Command, Redstone, AL. This economy was achieved by computerized cutoff of airhandling units in 125 buildings for a total of 435 hours during weekends and at night. The savings might have been greater except that the computer system had several days of "down time." Another recent study[5] by the Navy Civil Engineering Laboratory has indicated similar energy savings at Camp Pendleton, CA.

Energy conservation methods range from localized control devices such as time clock controllers to centralized, computer-based systems.[6] The localized energy control devices can be used economically and effectively in small or simple facilities to schedule automated equipment and outside air shutoff; however, when applied to sprawling military facilities, localized control poses a logistical problem[7] to the Facility Engineer (FE). In addition, the localized energy control system cannot provide the FE with readily available information about how, when, and where energy and other resources are being consumed. Such information is needed to upgrade present energy conservation and resource management procedures and to plan for more effective, reliable energy use in the future. Furthermore, the use of local controls has been curtailed for political and technical reasons in some instances[8] in favor of centralized computer-based ECSs.

The computer-based systems make it possible not only to conserve energy but also to monitor and control equipment and log its performance from a central location, thus saving "unproductive" manpower while providing reliable, cost-effective utility service. Many computer-based ECSs are commercially available for facility energy control. These conventional systems,

*Load shedding involves the shutdown and cycling of nonessential equipment during the peak electrical consumption periods, thus reducing peak demand. Reducing peak demand has a significant effect on the total billing from the utility supplier since rate schedules incorporate a demand charge that results in increased rates for several months after the occurrence of a large, short-term peak of usually 30 minutes. System performance optimization encompasses schemes such as enthalpy optimization, temperature reset, chiller load optimization, and filter pressure drop.

[1] *Feasibility Study of Automatic Load Control for Fort Belvoir, Virginia* (Reynolds, Smith and Hills, Inc., May 1976).

[2] *A Feasibility Study of Automation and Surveillance Systems for Utility Plants at Fort Leonard Wood, Missouri* (Burns and McDonnell, 1975).

[3] *A Report on the Economic Feasibility of an Energy Control System for Fort Monroe* (TRADOC, Director of Facility Engineering, 13 July 1976).

[4] "Computerization Cuts MICOM Electrical Costs", *Army Research and Development News Magazine* (Nov-Dec 1975), p 2.

[5] Roger I. Staab, *In-Service Evaluation of Camp Pendleton Monitoring and Control System*, Technical Memorandum M-62-76-14 (Navy Civil Engineering Laboratory, July 1976).

[6] *Automation and Centralization of Facilities Monitoring and Control Systems* (U. S. Army Facilities Engineering Support Agency, January 1976).

[7] Conversation with Mr. S. Sokalowski, Mechanical Engineer, TRADOC.

[8] *A Report on the Economic Feasibility of An Energy Control System for Fort Monroe* (TRADOC, Director of Facility Engineering, 13 July 1976).

which consist of remote sensors and control points linked to a central minicomputer, overcome many of the disadvantages of noncomputer, localized systems. When properly designed and programmed, they afford greater control flexibility and resultant increased energy efficiency; in addition, they provide a means of recording energy usage patterns which may later be examined to identify areas having the potential for greater economy.

Conventional computerized ECSs have some limitations. These systems are generally designed for application in commercial buildings or plants where the sites to be controlled are closer together than those at military bases. When such systems are installed in military facilities, there may be higher levels of data transmission interference because of the greater distances involved. In addition, a conventional computerized ECS loses all capability for monitoring and control from the central site in case of a breakdown of the computer system unless a standby computer is provided.

Other drawbacks of such systems relate to their bulky physical configuration and the difficulty of expanding them. The field cabinet to which the remote points are attached in each building is a bulky panel approximately 7 ft (2.1 m) high, and it is sometimes difficult to find enough space for such a unit. Furthermore, although the field cabinets are composed of standard components, the component configuration (the number and type of hardwired printed circuit boards and the order in which they are used) is custom-designed for each job. After the field cabinet is installed, adding sensors or controllers is difficult. For example, if a field cabinet was originally built to accept 70 analog points but 10 more will be added in the future, it will be necessary to install an additional field cabinet.

Most important, there is presently no hardware and software standardization among commercial ECS systems, because the manufacturers have no interest in enabling other companies to produce their components. This situation poses serious problems for the FE and District design personnel, because the ECS funding for an installation is frequently programmed over a long period of time and involves several separate procurement actions. Thus, without industry standardization, future expansion of an existing system is inevitably locked into the original ECS manufacturer—and usually costs more than the system installation. Since it is expected that most TRADOC and other installations will be equipped with ECSs in the near future, an ECS standard must be designed specifically for Army facilities. Such a standard would provide more effective and efficient system design, operation, updating, and expansion. With the advent of microprocessors, the Army standard ECS would consist of a centralized minicomputer for supervisory control with distribution microprocessors for monitoring and control of facility energy consumption.

To insure optimum ECS performance and cost/benefit ratio, this standardized system must be properly designed, evaluated, and specified. After an extensive literature search through engineering journals, publications, and standards, it is apparent that there are no ECS hardware and software standards. This is attributable to two factors. First, ECS application has been focused mainly on large commercial buildings and private institutions where the owner/management is usually concerned with one or two ECS installations. As a result, no one has attempted to standardize and unify ECS application in building energy and utility conservation, because the number of installations involved does not justify the need for an ECS standard. Second, the building's functional requirement does not change throughout its life; usually the installation is procured through a single action, and future expansion is minimal.

The software programs used in conventional ECSs are not interchangeable and the program listings and data communication formats are usually proprietary information. This makes verification and implementation of the process control schemes and programs impossible; all future implementations will thus have to be performed by the original equipment manufacturer. Furthermore, if three different types of systems are being used throughout the command, then three different implementations must be performed. In addition, full hardware documentation would be available in the Army standard ECS to insure competitive system expansion.

Only a few ECSs have been specified and reviewed by the Corps of Engineers and other military agencies,* so there is no broad base of experience upon which to

*Among the present installations are those at the Johnson Space Center, Houston, TX; West Point Military Academy, West Point, NY; Fort Benning, Columbus, GA; Fort Lee, Petersburg, VA; Fort Eustis, VA; Pease AFB, Hanover, NH; Fort Hood, Kileen, TX; Fort Bragg, NC; Camp Pendleton, San Diego, CA; and HQ, U. S. Army Missile Command, Redstone, AL.

draw when addressing these tasks. Efforts have been directed toward providing design guidelines and specifications for District design personnel and facility engineering groups. A design guidance document prepared by the Facilities Engineering Support Agency (FESA) provides information for evaluating designs, estimating costs, and establishing benefits of ECSs under consideration for existing facilities and new construction.[9] This document provides a step-by-step procedure for the field engineer to use in estimating the potential energy savings and costs of several types of control systems having various levels of sophistication. Design considerations are provided to aid District design personnel in preparing the scope-of-work statement for standardized ECS designs.

Objective

The objective of this study is to assess the feasibility of developing a standardized, distributed intelligence, computer-based energy control system designed specifically for conservation of energy at Army facilities.

Approach

This report examines the computer-based energy control and monitoring systems currently available from commercial sources (designated here as "conventional" systems), discusses the technical feasibility of developing a standardized Army system using distributed microprocessors coupled to a central minicomputer, and outlines the present industry standards for data transmission components which could be used in the latter type of system. Chapter 2 outlines the requirements for a standardized ECS, Chapter 3 reviews ECSs that are available commercially, Chapter 4 provides information on microprocessors and their potential for process control, Chapter 5 provides a review of interfaces, and Chapter 6 presents a comparison of the proposed system with a conventional system. Chapter 7 presents the preliminary conclusions drawn from the study conducted to date.

Scope

Since the required economic data were not available, this study has not fully assessed the cost-effectiveness of developing a standardized ECS for Army installations.

[9] *Automation and Centralization of Facilities Monitoring and Control Systems*, Report Number ED 76-1 (Army Facilities Engineering Support Agency, January 1976).

Mode of Technology Transfer

The results of this study will be published by Department of the Army as design criteria and guide specifications. The documentation may be a tri-service publication if recommendations by the Office of the Chief of Engineers are accepted.

2 DESIGN CRITERIA FOR ARMY ENERGY CONTROL SYSTEMS

An ECS designed to meet the Army's energy conservation mission should have the following attributes:

1. It should maximize the use of off-the-shelf electronic hardware such as sensors, controllers, data-acquisition modules with distributed intelligence, data communication modules, and a minicomputer for ease of operation and cost-effective future expansion. This requirement is necessary to ensure system update and expansion with standard hardware from suppliers other than the original equipment manufacturer.

2. It should provide standardized software in a high-level programming language (e.g., standard FORTRAN), so that it is not necessary for the user systems engineers, instrumentation engineers, and programmers to know the basic machine language of the computer involved or an assembly language for the machine. These engineers should be able to: (1) communicate with the system, (2) construct new programs and initiate or modify the sampling sequences to fit the specific need of the installation, and (3) perform data manipulation techniques through the use of standardized high-level language, a specialized process control program that can handle simple tabular formats, and/or an operator's console in some equally simple manner. Furthermore, the programming systems adopted should have machine and configuration independence as their long-range goals. In addition, they should contain provisions for automatic or semiautomatic documentation of all changes to the system's program and/or configuration. This requirement is necessary to insure compatibility and unification of software throughout all Army ECSs; it will enable ease of maintenance, updating, and expansion so that software changes do not have to be performed on a system basis.

3. The system should provide software systems that are developed in a modular fashion to the maximum extent possible; the functions and flow diagrams of the

modules should be rigidly defined. These modules should communicate through tables as much as possible. Table format should permit substitution of complete blocks to accommodate newer, more efficient forms as they are developed and should permit reassembly of the program without having to rework the other blocks.

4. The system should provide continuous, reliable, real-time facility energy monitoring and control with maximum overall system uptime. Furthermore, failure of any portion of the system should not impair the operation of the remainder of the system.

5. The system should minimize the skills necessary to make complex decisions. It should perform programmed automated equipment shut-off, outside air shut-off, electric demand shedding, system performance optimization, system efficiency monitoring, temperature reset, and equipment load optimization; it should be capable of readily expanding to include water treatment, exhaust effluent monitoring and control, and fire and building security tasks.

6. The system should be cost-effective.

7. The system should be easy to operate.

3 COMMERCIALLY AVAILABLE ENERGY CONTROL SYSTEMS

Levels of Energy Control Systems

There are three basic levels of automated energy control systems: level A, localized independent equipment control; level B, centralized noncomputer-based monitoring and control; and level C, centralized computer-based monitoring and control.

Level A, which is used mainly for localized independent control according to predetermined conditions and schedules, is the simplest type of energy control available. An example is a time clock control used to start/stop equipment at predetermined times.

Level B is used in small- to medium-sized building complexes for centralized energy monitoring and control. This level electronically scans the operating parameters of remote equipment and converts them to useful information. This information is then transmitted to the central console through permanently dedicated telephone lines or coaxial cables. Some examples of this level of control are a Honeywell Delta 2000 system, a Johnson Control JC-1000, or a Barber-Colamn Econ VI.

Level C is used for central computerized building energy supervisory control and management in large building complexes. Three basic monitoring and control functions generally performed by the level C systems are remote start/stop, energy consumption optimization, and building equipment preventive maintenance scheduling. Remote start/stop can be initiated by the operator or by the computer for energy conservation and "nonproductive" labor reduction. Manpower should be directed toward preventive maintenance of equipment, rather than toward "nonproductive" equipment status or logging activities that can be accomplished by machines. ECSs can use various system optimization schemes, such as outside-air economy cycle or exhaust air reduction, to maintain optimal system or apparatus efficiency; this conserves energy and decreases operating costs. Preventive maintenance scheduling can be used to properly maintain equipment before costly equipment failure and downtime occur.

This report is limited to the computerized monitoring control.

Centralized Conventional Computer-Based Energy Control System

A conventional computer-based ECS is a system in which control is accomplished either locally by hardwired logic or remotely by central computer software logic. Centralized control refers to monitoring and control of the on-off conditions of equipment, remote reset of the process conditions, and system optimization, etc. The term "centralized ECS" not only refers to the monitoring of operating status (on-off) and process value (temperature, pressure, etc.), but also includes security/fire alarm and environmental condition annunciation. Data are transmitted between the remote sensing/control points and the minicomputer-based central console via locally distributed remote panels in the communications network. Generally, the remote panel/loop is a nonintelligent input/output subsystem which consists of receivers, drivers, analog to digital (A/D) converters, digital to analog (D/A) converters, multiplexers, demultiplexers, modems, etc., for data conversion and transmission. The conventional system can generally be categorized into two classes, one with and one without hierarchy configuration.

Centralized Conventional ECS With Hierarchy Configuration

This system can be configured into a single- or multiple-loop system (Figure 1). In a single-loop system, the Central Processing Unit (CPU) operates the digital loop. In a multiple-loop system, the CPU monitors the operation of loops by communicating with each loop controller (LC). The CPU consists of a real-time computer, core and disc memory, and communications hardware. The loop controller may use a minicomputer for its operation, which can be connected to the CPU by dedicated wiring or leased telephone lines. For a single-loop system, each LC or CPU scans and monitors conditions of all remote points in its loop, and controls all information flow on the loop through the loop remote. In the multiple-loop system, if the LC detects a status change in a monitored point, it transmits that information to the CPU. The LC sends commands received from the CPU to the proper point and then monitors them for correct response. The LC interprets requests for information from the CPU and gathers and transmits the information to the CPU.

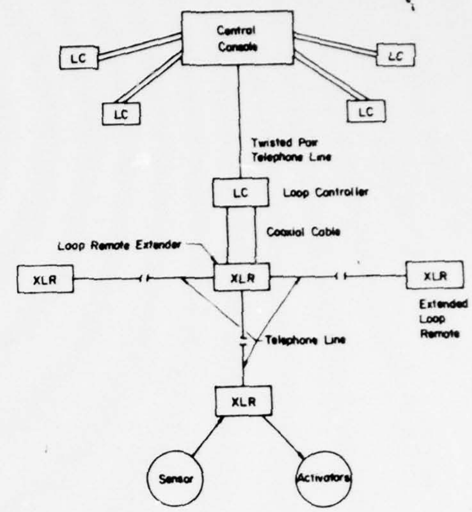

Figure 1. Loop system for centralized conventional ECS with hierarchy configuration.

Centralized Conventional ECS Without Hierarchy Configuration

The centralized conventional ECS without hierarchy configuration is a multi-channel system (Figure 2). The system sequentially scans remote data either by a high-speed analog and digital scanner or by a real-time central computer in the central console that uses remote data-gathering panels. The central computer provides real-time processing of the data gathered and monitors and controls remote points. Commands are output to remote points by either the central computer or the hardwired central processor under the direction of the central computer or computer operator. Each telephone line channel connected to the central console can serve a number of remote panels. The capacity of this type of system may vary greatly by manufacturer.

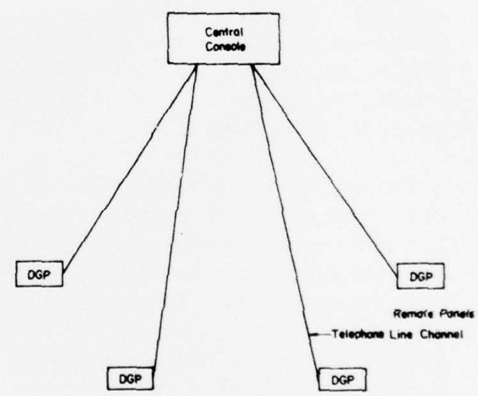

Figure 2. Centralized conventional ECS without hierarchy configuration.

System Capabilities

In either class of centralized ECS, the central computer or the loop controller is assigned time-consuming, repetitive, scanning tasks for all the remote points. All data must be processed in the central minicomputer and/or loop controller due to the lack of intelligence in the remote panels. Furthermore, all commands are initiated at the central computer and sent to the remote points.

All hardware and software is usually proprietary material supplied by one manufacturer; future expansion, implementation, maintenance, and training are therefore locked into this manufacturer. In addition, all conventional ECSs are incompatible with each other.

All systems can perform two basic functions: (1) remote start/stop, and (2) energy optimization. Examples of optimization programs are equipment optimization, enthalpy optimization, chiller optimization, remote temperature reset, boiler plant optimization, lighting optimization, demand limiting, and fan system optimization.

4 DISTRIBUTED MICROPROCESSOR-BASED ECS

General

Since general-purpose digital computers have been applied to industries for building energy control, methods to improve the system performance of centralized ECSs have been investigated carefully. It has been noted[10] that systems with distributed intelligence can improve system performance. In the past, this method was too expensive to be economically attractive due to the high cost of computing elements; however, since the introduction of the microcomputer, this method has been considered to be more feasible by users and manufacturers, and has been further enhanced by the continuous improvement of microprocessors. It is apparent that the microprocessor will revolutionize centralized energy control systems in that supervisory control functions performed by a single mini-computer and the monitoring and control functions will be redistributed among a number of microprocessor-based remote devices. Presently, the standardized ECS can be assembled from "off-the-shelf" electronic components, but lack of high-level language support for the microcomputers has made programming extremely difficult. Major effort has been initiated by microprocessor manufacturers to provide high-level language support for their products.[11]

Microprocessors are unique among integrated circuits (ICs) in that they can be programmed like computers. This capability enables a tradeoff of software for hardware, which increases system capability and versatility. When the control scheme or monitoring sequence must be updated, only the microprocessor's memory is updated or replaced. The mass of memory chips can be purchased or reprogrammed at a low cost, and there are no circuits to be tested.

In addition, when many functions must be performed, the microprocessors can be used economically to replace or upgrade random logic designs that involve many standard ICs. In addition, microprocessors use fewer IC components than hardwired logic in applications emphasizing random collection and routing of data. This capacity enhances the overall system maintainability because the standardized ECS will contain fewer customized hardwired logic circuits in each remote panel, thus decreasing system testing and troubleshooting time.

Currently, microprocessors are most commonly used as a dedicated controller or as a low-level component of a larger system. Popular microprocessors are generally produced by more than one manufacturer, thus insuring parts availability. The major disadvantage of microprocessors is that the lack of high-level language confines programming effort to assembly or machine level language. In general, programming of microprocessors is very difficult; however, manufacturers are expending major effort to provide high-level language support for their microprocessors.

Configuration and Description of Proposed System

System Hierarchy

To enhance the operator's performance, the concept of a centralized control room remains unchanged. The user will obtain a distributed system having a display, access, and control ability in the central control room and a monitoring and control capability in the field. The system will consist of different sized processors interconnected to form a fixed hierarchy (see Figure 3). Remote controllers, which will be located strategically over the entire military base, should be near the equipment they will control. To keep data transmission costs down, serial data transmission should link the remote controller to the central computer. The minicomputer at the central site will control the data transmission to and from the remote controllers, while the remote controllers act as local controllers. Information routed to the central processor from remote controllers is the data needed for logging, displaying, or supervisory control calculation; remote controllers will perform most of the rudimentary monitoring and control functions. If the central minicomputer breaks down or there is a power failure, the remote controllers can continue to operate on battery packs. Together with the system's uninterrupted monitoring and control abilities, these capabilities provide unmatched reliability on a security system. In addition, fully documented data transmission protocol and hardware will enable unmatched system expandability.

System Component Description

Central Computer. The system's central computer will be a minicomputer. The microcomputer, which had been considered for use as a central processor,

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[10] Considine, et al., *Process Instruments and Control Handbook*, Second Ed. (McGraw-Hill Book Company, 1974), Chapter 17.

[11] *Proceedings of the Third Annual Advanced Control Conference*, Sponsored by Control Engineering and the Purdue Laboratory for Applied Industrial Control (Control Engineering, 1976), pp 19-48.

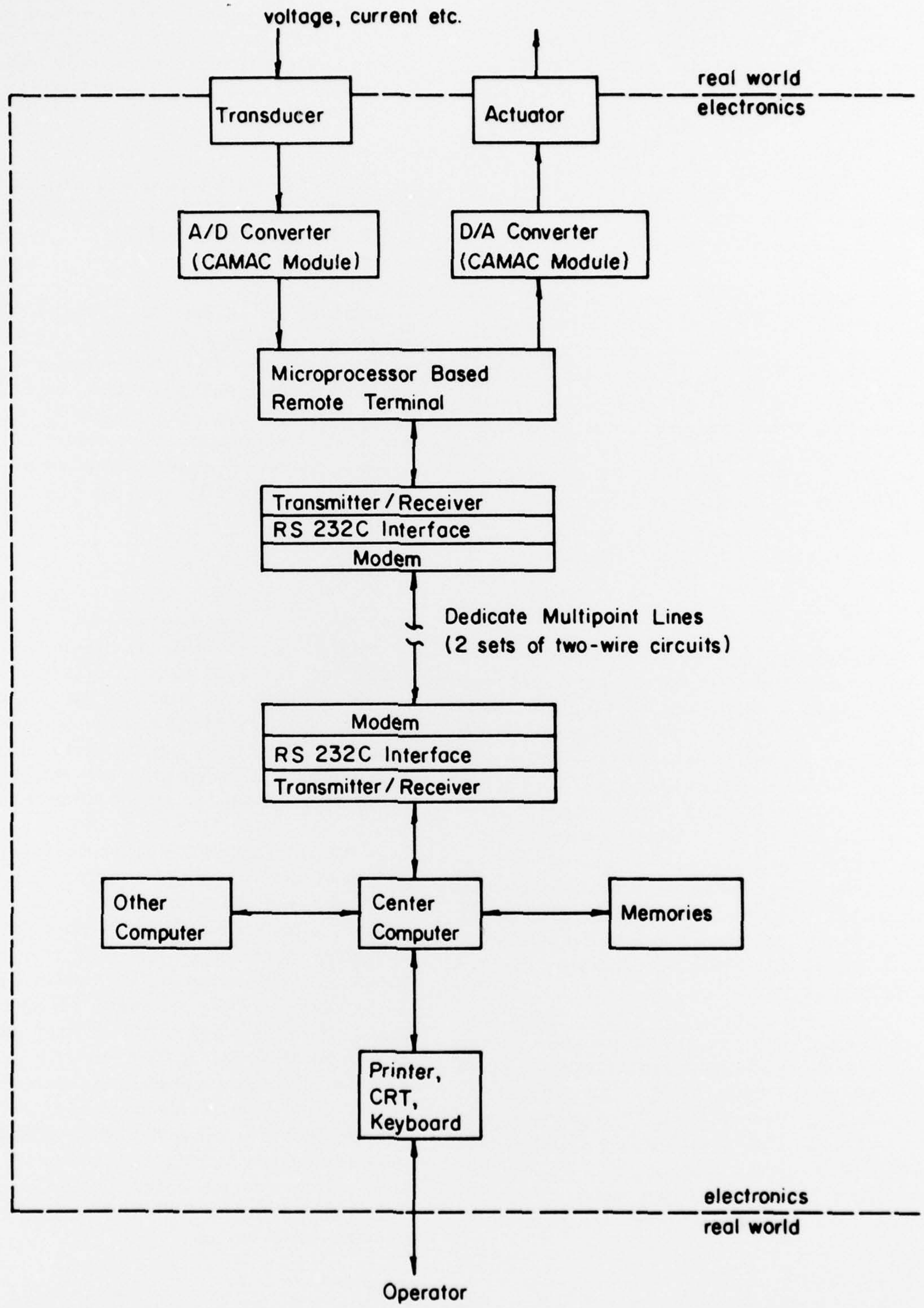

Figure 3. Fixed hierarchy formed by various sized interconnected processors.

lacks system software (high-level language compilers, assorted real-time operating systems, debugging systems, and software libraries); in addition, its arithmetic capabilities make it unsuitable for performing complex optimization and other supervisory functions which are now major tasks of the central minicomputer. The interfacing requirement of such standard peripheral devices as the printer, CRT, and disc also make the minicomputer more attractive, since interfaces are usually available as off-the-shelf items.[12]

Remote Controller. The remote controller is a microprocesser-based device. In comparison to the minicomputer, it may have shorter word length, limited instruction set, slower speed, fewer internal registers, and less sophisticated interrupt capabilities, but it still contains enough computing power and input/output (I/O) capability to perform both status monitoring and control functions and simple arithmetic operations. Since monitoring and control functions are programmed into each microprocessor memory, the remote controller can be readily adapted to different application requirements by simply reprogramming or replacing its memory clip.

Communication Network. The communication network is a multi-point line. The configuration operates in a half-duplex mode (two-way alternate) and is implemented on a duplex four-wire circuit (an out-bound channel from a central point to all remote receivers and an in-bound channel to be shared by the remote transmitters). The four-wire half-duplex system eliminates turnaround time and thus increases system efficiency. The centralized minicomputer controls the flow of information to and from each remote controller by transmitting an address code to the selected remote controller. The selected controller then transmits a signal back to the minicomputer indicating that it is ready to receive instructions.

In contrast to the centralized operation, noncentralized operation allows all stations to receive signals from any other station and allows any station to be selected as the "control station." One disadvantage of this is that one station may interfere with the transmission of data from another. If part of the data being transmitted coincides with the address of another terminal, the data will be garbled, and there will be a serious recovery problem. This problem does not occur in a four-wire half-duplex centralized operation, in which data between the central station and remote stations are transmitted in two separate dedicated lines.

5 DEVELOPMENTAL CONSIDERATIONS FOR ECSs DESIGNED SPECIFICALLY FOR ARMY FACILITIES

Generally, an interface is a common boundary between components of one system or several different systems. It contains logic circuits necessary for signal level transformation, coding/decoding, data formatting, synchronization, and operations control. Optimally, the interface requirements will conform to a set of industrial and governmental standards that will provide for efficient future system expansions and modifications.

Input/Output (I/O) Interface

The input interface consists of A/D converters, multiplexers, and logic circuits which are necessary to control the converters and multiplexers and to supply the computers' internal registers with information in digital form. Generally, the control output interface consists of (1) D/A converters and demultiplexers and (2) necessary logic circuits to obtain binary digital values from the computer for conversion to the analog outputs which drive the controllers or actuators.

In the past, analog I/O interfaces were custom-built and matched to a microprocessor for each application.[13] However, the recent advance in semiconductor technology has enabled manufacturers and electronic equipment vendors to produce off-the-shelf data acquisition modules which can be interfaced easily to microprocessors (Table 1). Analog I/O interface designed for microcomputers such as Intel SBC 80/10 and MDS-800, Intellec 8, Motorola EXORciser, and National IMP-16C are available from subassembly manufacturers like Data Translation, Inc., Datel Systems, Inc., and Burr-Brown (Table 2). At the present rate of electronic industry progress, standardized I/O systems which can be interfaced directly into microcomputers will soon be available as off-the-shelf items from subassembly manufacturers.

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[12] H. P. Zinschlog, W. E. Long, and J. A. Conover, "LSI and Process Control," *Instrumentation Technology* (November 1975), pp 47-52.

[13] H. P. Zinschlog, W. E. Long, and J. A. Conover, "LSI and Process Control," *Instrumentation Technology* (November 1975), pp 47-52.

Table 1
Data Acquisition Modules

Manufacturer	Module No.	Input Range	Tri-State Output	Throughout	Channel No.	Resolution	Price
Analog Devices	DAS1128			50 kHz	16	12 bits	295
Analogic	MP6812	±10,±24vMAX	Yes	30 kHz	16	12 bits	295
Data Transmission	DT5710A	0–10v.±10v 0–5v.±5v	Yes	125 kHz	16	12 bits	675
Data Transmission	DT5701	0–10v.±10v 0–5v.±5v	Yes	35 kHz	16	12 bits	175*
Datel Systems	MDAS-16	0–10v.0–5v ±10v.±5v.±2.5v	Yes	75 kHz	16	12 bits	295
Burr-Brown	SDMB50	0–10v.0–5v ±15v.±10v.±5v		100 kHz 50 kHz	16	8 bits 12 bits	595
Micro Networks	MN7100	±10v		90 kHz	8	8 bits	195

*Price for 100-PC lots

Table 2
Analog Input/Output Systems

Manufacturer	Model No.	Input Channels	Output Channels	Input Range	Output Range	Resolution	Throughout	Motherboard	Price*
Data Translation	DT1751	16	2			12 bits		Intel SBC80/10	1195 (795)
Datel Systems	Sine Trac 800	32				12 bits	75 kHz	"	845
" "	Sine Trac 800D		8			8 bits		"	695
Data Translation	DT1722	16		±10v,±5v 0–10v,0–5v 4–20mA		12 bits	25 kHz	IMP-16C	1195
Burr-Brown	MP7216	16		±10v		12 bits	33 μsec[1]	Motorola EXORciser	695 (295)
" "	MP8416	16		"		"	"	Intel SBC80/10	"
" "	MP8216	16		"		"	"	Intellec 8	"
" "	MP7104		4		±10v 0–10v	"	10 μsec[2]	Motorola EXORciser	"
" "	MP8304		4		±5v 0–5v	"	"	Intel SBC80/10	"
" "	MP8104		4		±2.5v @5mA	"	"	Intellec 8	"

*Price in parenthesis is for 100s

[1]Conversion time
[2]Settling time

Communication Interface

The interface between the data terminal equipment (minicomputer) and the data communication equipment (modem or DCE) in the communication network should be consistent with the Electronic Industries Association (EIA) Standard RS-232-C.

Since the minicomputer is the only transmitter on the outbound channel, the type E duplex interface (Tables 3 and 4) can be used and the outbound channel line signal left activated (turned on) at all times. As soon as the Data Set Ready Circuit (CC) (Table 5) is switched to "on," the transmitted line signal will be switched to "on" and the Clear to Send Circuit (CB) will be activated to indicate "on." The line signals can be removed only when the power to the modem (DCE) has been deactivated. Since all the remote terminal transmitters share the same in-bound telecommunication channel, the type D duplex (half-duplex mode) interface can be used; after each data transmission, the remote terminal transmitters must deactivate the Request to Send Circuit (CA). Remote or central terminal reception is facilitated by insuring that the circuit CC and the Received Line Signal Detector Circuit (CF) are activated. Furthermore, the circuit CA will be activated by the remote terminal when the remote terminal is asked to respond. Data are transmitted on the Transmitted Data Circuit (BA) and received on the Received Data Circuit (BB). The Signal Ground Circuit (AB) is required to establish the common ground reference potential for the other interchange circuits.

To minimize data transmission cable cost, serial communication will be used between the central and the remote stations. Development of transmitter/receiver interfaces to convert parallel data to serial data and back to parallel is necessary to provide efficient data use by the minicomputer and the microprocessors. Generally, a transmitter interface will consist of parallel

Table 3
Interface Types for Data Transmission Configurations
(From "Application Notes for EIA Standard RS-232-C,"
***Industrial Electronics Bulletin*, No. 9 [May 1971]).**

Data Transmission Configuration	Interface Type
Transmit Only	A
Transmit Only*	B
Receive Only	C
Half Duplex	D
Duplex*	D
Duplex	E
Primary Channel Transmit Only*/Secondary Channel Receive Only	F
Primary Channel Transmit Only/Secondary Channel Receive Only	G
Primary Channel Receive Only/Secondary Channel Transmit Only*	H
Primary Channel Receive Only/Secondary Channel Transmit Only	I
Primary Channel Transmit Only*/Half Duplex Secondary Channel	J
Primary Channel Receive Only/Half Duplex Secondary Channel	K
Half Duplex Primary Channel/Half Duplex Secondary Channel	L
Duplex Primary Channel*/Duplex Secondary Channel*	L
Duplex Primary Channel/Duplex Secondary Channel	M
Special (Circuits specified by Supplier)	Z

Note: Data transmission configurations identified with an asterisk (*) indicate the inclusion of circuit CA (Request to Send) in a one way only (transmit) or duplex configuration where it might ordinarily not be expected, but where it might be used to indicate a nontransmit mode to the data communication equipment to permit it to remove a line signal or to send synchronizing or training signals as required.

Table 4

Standard Interfaces For Selected Communication Systems Configurations (From "Application Notes for EIA Standard RS-232-C," *Industrial Electronics Bulletin*, No. 9 [May 1971]).

Interchange Circuit		Interface Type													
		A	B	C	D	E	F	G	H	I	J	K	L	M	Z
AA	Protective Ground	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BB	Signal Ground	x	x	x	x	x	x	x	x	x	x	x	x	x	x
BA	Transmitted Data	x	x		x	x	x		x		x		x	x	o
BB	Received Data			x	x	x		x		x		x	x	x	o
CA	Request to Send		x		x		x				x		x		o
CB	Clear to Send	x	x		x	x	x		x		x		x	x	o
CC	Data Set Ready	x	x	x	x	x	x	x	x	x	x	x	x	x	o
CD	Data Terminal Ready	s	s	s	s	s	s	s	s	s	s	s	s	s	o
CE	Ring Indicator	s	s	s	s	s	s	s	s	s	s	s	s	s	o
CF	Received Line Signal Detector			x	x	x		x		x		x	x	x	o
CG	Signal Quality Detector														o
CH/CI	Data Signalling Rate Selector (DTE) / (DCE)														o
DA/DB	Transmitter Sig. Element Timing (DTE) / (DCE)	t	t		t	t	t		t		t	t	t	t	o
DD	Receiver Signal Element Timing (DCE)			t	t	t		t		t		t	t	t	o
SBA	Secondary Transmitted Data							x		x	x	x	x	x	o
SBB	Secondary Received Data						x		x		x	x	x	x	o
SCA	Secondary Request to Send							x			x	x	x		o
SCB	Secondary Clear to Send							x		x	x	x	x	x	o
SCF	Secondary Received Line Signal Detector						x		x		x	x	x	x	o

Legend: o - To be specified by the supplier
– - optional
s - Additional interchange circuits required for switched service
t - Additional interchange circuits required for synchronous channel
x - Basic interchange circuits, all systems

data input lines, a holding register to load and hold input data, a shifting register to convert parallel data to serial data, and control logic to supervise internal operations. Control inputs are generally provided to load the input data into the holding register, to enable parity, and to select odd/even parity, character length, baud rate, and the number of stop bits. Control word from the minicomputer is required to drive these inputs. The transmitter usually has status outputs to indicate full/empty status for both the holding and the shifting registers. The receiver usually has a shifting register and a holding register to drive the parallel data output lines. It also has control inputs to load the holding register, to enable parity, and to select odd/even parity, character length, baud rate, and the number of stop bits.[14]

[14]F. W. Etcheveny, "Binary Serial Interface-Making the Digital Connection," *EDN* (April 20, 1976), pp 40-43.

Peripheral Interface

Generally, each peripheral device has its own way of transmitting and/or receiving data from the computer; thus, to make input/output compatible, there must be interfaces between the computer I/O bus and each peripheral device to relate the signals required by the I/O bus to the signals provided by the peripheral device, and vice versa. Minicomputer manufacturers offer standard interfaces that enable direct plug-in of peripheral devices such as discs, tape cassettes, printers, and cathode ray tubes to the minicomputer.[15]

Multipoint Line Control[16]

Since all the remote transmitters are connected to the same data bus, only one remote terminal can transmit or receive information at one time. Line control

[15]H. P. Zinschlog, W. E. Long, and J. A. Conover, "LSI and Process Control," *Instrumentation Technology* (November 1975), pp 47-52.

[16]*Teleprocessing Network Organization* (Prentice-Hall, Inc., 1970).

Table 5
EIA Standard RS-232-C Signals

Interchange Circuit	CCITT Equivalent	Description	Ground	Data		Control		Timing	
				From DCE	To DCE	From DCE	To DCE	From DCE	To DCE
AA	101	Protective Ground	X						
AB	102	Signal Ground/Common Return							
BA	103	Transmitted Data			X				
BB	104	Received Data		X					
CA	105	Request to Send					X		
CB	106	Clear to Send				X			
CC	107	Data Set Ready				X			
CD	108.2	Data Terminal Ready					X		
CE	125	Ring Indicator				X			
CF	109	Received Line Signal Detector				X			
CG	110	Signal Quality Detector				X			
CH	111	Data Signal Rate Selector (DTE)					X		
CI	112	Data Signal Rate Selector (DCE)				X			
DA	113	Transmitter Signal Element Timing (DTE)							X
DB	114	Transmitter Signal Element Timing (DCE)						X	
DD	115	Receiver Signal Element Timing (DCE)						X	
SBA	118	Secondary Transmitted Data			X				
SBB	119	Secondary Received Data		X					
SCA	120	Secondary Request to Send					X		
SCB	121	Secondary Clear to Send				X			
SCF	122	Secondary Rec'd Line Signal Detector				X			

DCE = Data Communications Equipment (Modems)
DTE = Data Terminal Equipment (Terminal)

procedure is required to control and supervise remote terminal communication with the minicomputer. In the multipoint line organization, the central console polls the remote terminals individually to see whether they have any data to transmit. This process is called "read poll." If a remote terminal has nothing to send, a negative reply will be sent to the minicomputer, which will then poll the next terminal. Otherwise, the remote terminal will start transmitting data to the central console. When the central console receives the data without any error, it sends a control character to the remote terminal to acknowledge that the remote data have been received and checked for error. At the completion of the transmission process, the remote terminal sends an end-of-transmission signal to the central console; when this signal has been acknowledged by the central console, the sending terminal relinquishes the line by deactivating the Request to Send Circuit (CA) and goes into a standby mode. The central console then polls the other terminals individually. If a transmission error is detected, the central console will send a control character to the terminal to request the data again. The error checking procedure is done automatically each time data are transmitted.

In the write poll, the central console selects a remote terminal and asks whether it is ready to receive a message. The terminal replies "yes" or "no" by sending the appropriate signal back to the central console. If the reply is "yes," the central console sends the data to that terminal. If the remote terminal detects no transmission error, it acknowledges receipt of the message, and the central console continues the polling; however, if it detects a transmission error, it will ask that the data be retransmitted. If error still exists after the data have been retransmitted a predetermined number of times, the central console will notify the operator that the link is down.

Parity check is used to detect transmission errors.

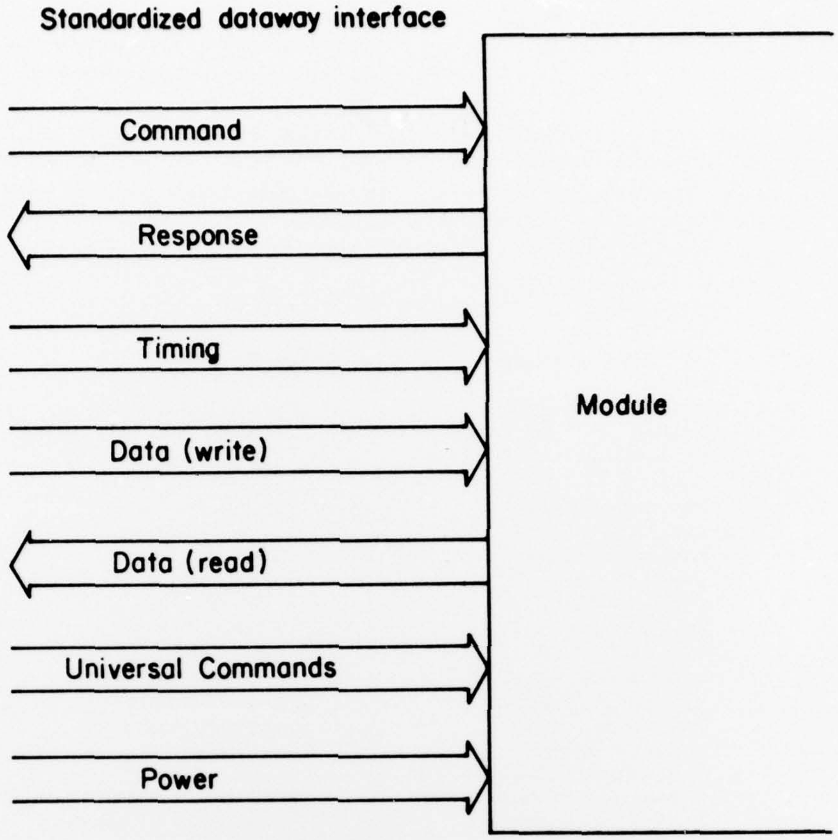

Figure 4. The basic dataway interface to a CAMAC module.

CAMAC (Computer Automated Measurement and Control) Interface System[17]

Modularity enables rapid system modifications for meeting new demands and allows functional modules to be tested independently before they are assembled into a complex system, thus saving valuable system checkout time. Furthermore, modules can be replaced rapidly, which minimizes system downtime. If standardization is added to modularity, the advantages are greater. One standardized module can be used for many systems, resulting in higher volume of production, less custom engineering, and eventually, a lower price. CAMAC, which represents a modular approach to interfacing, is a digital interfacing standard that is particularly appropriate for a computer-oriented data and control system. It has been adopted as an Institute of Electrical and Electronics Engineers (IEEE) standard.

The basis of the CAMAC system is the "crate" that houses the interfacing modules. A dataway or motherboard at the rear of the crate provides a digital pathway between the modules. This dataway is carefully standardized to insure interchangeability of modules (Figure 4), yet it is generalized enough to permit the various functions necessary for the modules to control and/or measure physical processes. The internal makeup of the modules is not specified. The single interface to the external controller is made via a module inserted

[17] Dale Horelick and R. S. Larsen, "CAMAC: A Modular Standard," *IEEE Spectrum* (April 1976), pp 50-55.

at the right side of the crate (the crate controller). With the advent of microprocessors, a controller or microcomputer can be housed in the crate controller.

Table 6 shows the commercially available CAMAC hardware. Although this table lists manufacturers, some of these products are available directly from computer firms. The types and variety of components and subsystems available are increasing rapidly in response to user demand. Most suppliers respond rapidly to demand for new items, especially functional modules, which quite often are developed in direct response to user specifications. This, together with the advantages of modular standard, suggests that CAMAC may be used in ECSs as a standard method of interfacing the physical phenomenon with the computer or remote controller.

Table 6
Sampling of Commercially Available CAMAC Hardware

1. *Modules–general purpose*
   - Counters
   - Counters-preset
   - Timers
   - Input register-parallel
   - Input register-serial
   - Input-output register
   - Input register-isolated
   - Clock generators
   - Pulse generators
   - Word generators
   - DVM modules
   - Pulse duration demodulator
   - Output register-parallel
   - Output register-serial
   - Output register-isolated
   - Stepping motor controller
   - Output register-relay
   - Dataway display module
   - Look-at-me (LAM) grader
2. *Multiplexers and converter modules*
   - Analog multiplexer
   - Sample-and-hold multiplexer
   - Analog-digital converter
   - Time-digital converter
   - Digital-analog converter
   - Synchro-digital converter
   - Integrator-ADC
   - Digital multiplexer
   - Code converter module
3. *Peripheral interface modules*
   - Paper tape reader
   - Card reader
   - Line printer
   - Cassette tape control
   - TTY control
   - CAMAC-CAMAC data link
   - Graphic display
   - Display plotter
   - Display vector generator
   - Display systems
   - Serial I/O register
   - Buffer memory
   - Magnetic tape control
4. *Crate controller modules*
   - Type A-1 parallel
   - Type L-1 serial
   - Dedicated single-crate (type U) for:
     - DEC PDP-8
     - DEC PDP-11
     - DG Nova
     - HP 2100 series
     - Varian 620 series
     - Mod comp
   - Manual crate controller
   - Autonomous or microprocessor single-crate controller
5. *Branch drivers, extenders*
   - Parallel branch drivers for:
     - DEC PEP-8
     - DEC PDP-9
     - DEC PDP-11
     - DEC PDP-15
     - HP 2100 series
     - Varian 620 series
     - DG Nova/Supernova
     - Interdata 70 series
     - Honeywell 316/516
     - Siemens 320/330, 404/3
     - General Automation SPC 16
     - Microdata 800/CIP 2000
     - Autonomous Systems
     - Prime Computers
   - Parallel branch extender
   - Serial branch driver
   - Serial branch extender
   - Serial driver-manual
6. *Crates and associated hardware*
   - Crates, powered
   - Crates, unpowered
   - Module kits
   - Power supplies

6 ADVANTAGES OF THE PROPOSED DISTRIBUTED SYSTEM OVER THE CONVENTIONAL ECS

General

A conventional energy control system is usually procured in entirety from one manufacturer; thus, contracts for future expansion will be limited to the original manufacturer, which usually increases cost. Furthermore, data acquired at remote terminals of a conventional ECS are transmitted through a communication network to the central console for processing rather than being processed locally; this may increase the probability of transmission error and may reduce system reliability.

A system designed specifically for Army facilities can be implemented with off-the-shelf modules, and its intelligence distributed among remote terminals to relieve the minicomputer of some functions and improve overall performance.

As compared with the conventional ECS, the proposed distributed system offers six significant advantages:

1. Standardized hardware and software. Hardware and software modules for the systems installed in military bases will be unified and standardized to facilitate use, implementation, and maintenance.

2. Higher overall performance and overall reliability. The incorporation of microprocessors relieves the central computer from direct monitoring and control functions so that it can be used full-time for more complex tasks; remote terminals can perform the basic monitoring and control functions, thus increasing overall performance. On the other hand, remote terminals can remain operational while the central computer is down, which assures maximum uptime for real time application[18], such as fire and security monitoring. In addition, redundant microprocessors can be included to back up terminals which monitor and control critical points.

3. Higher system security. Since most data terminations and command origins are initiated at remote terminals, the volume of communications between remote terminals and the central computer—as well as transmission distances—are significantly decreased. This reduces the probability of error correspondingly.[19]

4. Expandable. Modularity introduced by the distributed system makes total step-by-step automation much easier.[20] This system can be expanded gradually as determined by the need and availability of capital.

5. Flexible design. When demand changes at a remote site, only the remote terminal is affected in the distributed system. Furthermore, microprocessor-controlled remote terminals may be added or removed without disturbing the rest of the system.[21] However, in the centralized energy control system, the entire system would have to be shut down and tested.

6. Additional benefits may be derived in having systems for which maintenance and training are standardized and additions and parts can be obtained competitively.

7. System cost. In the conventional computer-based ECS having 1250 points, the average estimated initial cost per point is approximately \$800;[22] one-third of this amount is associated with remote point cost. It has been estimated that using a system with distributed intelligence can decrease the system cost per remote point to \$550.[23]

System cost for a standard ECS was estimated from instrumentation and process control system information (Table 7). After development, the production cost of the system will be approximately \$690,000 for an ECS having 1250 remote points, a savings of \$310,000 per installation. At this savings, the break-even point would be use of ECS at eight installations.

[18] A. J. Weissberger, "Distributed Function Microprocessor Architecture," *Computer Design* (November 1970), pp 77-83.

[19] A. J. Weissberger.

[20] "Engineering Evolution of Industrial Computer Systems," *Computer Design* (April 1972), pp 45-46.

[21] A. J. Weissberger.

[22] *Feasibility Study of Automatic Load Control for Fort Belvoir, Virginia* (Reynolds, Smith and Hills, Inc., May 1976); *A Feasibility Study of Automation and Surveillance Systems for Utility Plants at Fort Leonard Wood, Missouri* (Burns and McDonnell, 1975); and *A Report on the Economic Feasibility of An Energy Control System for Fort Monroe* (TRADOC, Director of Facility Engineering, 13 July 1976).

[23] Considine, et al., *Process Instruments and Control Handbook*, Second Ed. (McGraw-Hill Book Company, 1974) Chapter 17.

Table 7
Estimated Standard Army ECS Prototype Development Cost

Item	Development Cost (Thousands $)
a. Guideline for remote Input/Output activities organization (i.e., assignments of devices to microprocessors) so that system can be efficiently implemented.	$ 75
b. Development of software and hardware input/output interfaces.	125
c. Development of communication interface.	500
d. Specifications of display and output format.	150
e. Development of distributed intelligent ECS microcomputer.	400
f. System and control software development.	1,250
g. Sensors and installation.	500
	$3,000

7 CONCLUSIONS

A standardized energy control system (ECS) designed for energy conservation in Army fixed facilities is feasible. The system consists of a centrally located minicomputer for base-wide supervisory control and numerous strategically located microprocessor-based devices capable of performing real-time uninterrupted energy and utility monitoring and control. It can be assembled from "off-the-shelf" components which are currently available and operational in the process control and instrumentation industries. While software for the system is not complete, major effort has been initiated by the microprocessor manufacturers to provide high-level language support for their products.

The proposed standard ECS has several advantages over a conventional ECS composed of a centralized minicomputer and numerous data gathering panels:

1. The use of standardized industrial input/output (I/O) interface specifications will enable the use of subcomponents from other than the original equipment manufacturer.

2. Standardized hardware and software modules afford the system greater expandability because, as the need arises and capital becomes available, modules can be added without impairing the rest of the system.

3. Operational and maintenance procedures will be standardized.

4. Future implementation of the software and hardware for the standardized system will be more efficient, because they will be unified.

5. The system is designed to fail "gracefully," in that the distributed microprocessor-based devices will continue to monitor and control energy consumption when the centralized minicomputer is down, thus eliminating the need for an expensive backup minicomputer. During power failures, the microprocessor-based devices can be run on battery pack, providing the installation with uninterrupted monitoring and control. When the monitoring and control demand changes, only the microprocessor-based device is affected.

6. The distributed microprocessor-based devices should improve overall system performance by decreasing the amount of data communication that has to be performed between the central minicomputer and the actual processing points.

Furthermore, a standardized ECS is estimated to be less expensive to build than a conventional system, based on first cost data obtained from equipment manufacturers and catalog sources. A commercially available system of 1250 points at an initial cost of $800 per point would cost $1,000,000. The proposed system is estimated to cost $690,000 for 1250 points. Development cost for a prototype standardized ECS is estimated to be $3,000,000. At a savings of $310,000 per installation, the breakeven point would be eight installations.

7. It can be concluded that a demonstration of this concept would be the appropriate next step.

CITED REFERENCES

A Feasibility Study of Automation and Surveillance Systems for Utility Plants at Fort Leonard Wood, Missouri (Burns and McDonnell, 1975).

A Report on the Economic Feasibility of an Energy Control System for Fort Monroe (TRADOC, Director of Facility Engineering, 13 July 1976).

"Application Notes for EIA Standard RS-232-C," *Industrial Electronics Bulletin*, No. 9 (May 1971).

Automation and Centralization of Facilities Monitoring and Control Systems (U. S. Army Facilities Engineering Support Agency, January 1976).

"Computerization Cuts MICOM Electrical Costs," *Army Research and Development News Magazine* (Nov-Dec 1975), p 2.

Considine, et al., *Process Instruments and Control Handbook*, Second Ed., (McGraw-Hill Book Company, 1974), Chapter 17.

Denmark, Anthony M., "Distributed Control Boosts Process Reliability," *Electronics* (April 15, 1976), pp 163-164.

"Engineering Evolution of Industrial Computer Systems," *Computer Design* (April 1972), pp 45-46.

Etcheveny, F. W., "Binary Serial Interface–Making the Digital Connection," *EDN* (April 20, 1976), pp 40-43.

Feasibility Study of Automatic Load Control for Fort Belvoir, Virginia (Reynolds, Smith and Hills, Inc., May 1976).

Horelick, Dale and R. S. Larsen, *CAMAC: A Modular Standard, IEEE Spectrum* (April 1976), pp 50-55.

Proceedings of the Third Annual Advanced Control Conference Sponsored by Control Engineering and the Purdue Laboratory for Applied Industrial Control (Control Engineering, 1976), pp 19-48.

Staab, Roger I., *In-Service Evaluation of Camp Pendleton Monitoring and Control System*, Technical Memorandum M-62-76-14 (Navy Civil Engineering Laboratory, July 1976).

Teleprocessing Network Organization (Prentice-Hall, Inc., 1970).

Weissberger, A. J., "Distributed Function Microprocessor Architecture," *Computer Design* (November 1970), pp 77-83.

Zinschlog, H. P., W. E. Long, and J. A. Conover, "LSI and Process Control," *Instrumentation Technology* (November 1975), pp 47-52.

UNCITED REFERENCES

Lewis, Donald R. and W. Ralphsiena, "Clearing the Interface and Software Hurdles," *Microprocessors–New Directions for Designers* (Hayden Book Company, Inc., 1975), pp 73-77.

Mason, John F., "From Data to Process Systems, Microprocessors are Reshaping Designs," *Electronic Design* (January 5, 1976), p 42.

Smith, Cecil L. and Marcel T. Brodmann, "Process Control Trends for the Future," *Chemical Engineering* (June 21, 1976), pp 129-134.

Woks, David J., "Designing Minicomputer Hardware/Software Systems–the System Approach, *A Practical Guide to Minicomputer Applications* (IEEE), pp 59-60.

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Ft Eustis, VA 23604
USAIC
Ft Benning, GA 31905
USAAVNC
Ft Rucker, AL 36361
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Ft Leavenworth, KS 66027
USACC
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TRADOC
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Ft McClellan, AL 36201
Ft Sill, OK 73503
Ft Bliss, TX 79916
HQ, 7th Inf Div & Ft Ord, CA 93941
HQ, 24th Inf & Ft Stewart, GA 31313
HQ, 1st Inf Div & Ft Riley, KS 66442

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Little Rock AFB
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ATTN: Building Research Advisory Board
ATTN: Library of Congress (2)
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